CCV

LONGER COMBINATION VEHICLES

OPERATIONAL TEST

California Department of Transportation

March 1984

EXECUTIVE SUMMARY

Sections 138 and 415 of the 1982 Surface Transportation Assistance Act require the Federal Highway Administration to report to Congress "on the benefits and costs--of a national intercity truck route network for--longer combination--vehicles". To help determine how well these longer combination vehicles (LCV's) could operate over today's roadways, the California Department of Transportation (Caltrans) volunteered to conduct an actual over-the road, operational test of three LCV combinations. This report describes the Caltrans observations of the operational tests of Triple Trailers, Rocky Mountain Doubles, and Turnpike Doubles.

Each combination was operated over essentially the same 1,200-plus mile route, allowing both observations of each combination and a direct comparison between the combinations. The report covers the observations in the areas of: freeway interchanges, open-road travel, urban traffic (including arterials and intersections), narrow lanes, two-lane roads, other freeway facilities such as rest areas and scales, off-tracking, speed on grades, braking, acceleration, travel during rain and wind, noise generation, and fuel economy.

TRIPLE TRAILER

The Triple Trailer combination consisted of a tractor, a 28-foot semitrailer and two 28-foot trailers. This combination had an overall length of 100.2 feet while using a two-axle cab-over-engine tractor and a length of 107.4 feet using a three-axle conventional tractor. When loaded, this combination had a gross vehicle weight of 111,000 pounds.

The Triple Trailer combination was the most maneuverable of the three combinations as witnessed by the off-tracking tests and travel through numerous interchanges and intersections. Generally, this combination could maneuver almost as well as other observed long tractor-semitrailer combinations mandated by the 1982 Surface Transportation Assistance Act (STAA) to operate over the Designated System.

The Triples, however, had a continual (over 75 percent of the mileage) sideways sway of four to six inches while traveling over the open road segments. This condition, observed for the two different triples combinations, at times increased to well over one foot and had a noticable effect on adjacent traffic. This observation closely matches that of a 1,500 mile test of Triple Trailers conducted by Caltrans in 1971.

The Triples, as well as the other LCVs, had an impact simply because their dimensions differentiated them from other large trucks. Having the same 102-inch width as allowed by the STAA, there was no major difference between the Triples and other large trucks while operating on narrow lanes or straight two-lane roads. However, the Triples did have a noticeable and more severe impact in such areas as urban arterials, roadside rest areas, and truck weight scales where the longer length exceeded the current design standards or simply required more room than other large trucks.

Similarly, because of the heavier gross vehicle weights, the acceleration and speed on grades for the Triples was slower than that observed for other large trucks. These weight related observations would argue for minimum standards to minimize the impact of LCVs on other traffic.

In the braking tests, the additional number of axles and tires appeared to compensate for the additional weight and allowed the Triples to stop in roughly the same distance as the large semi. Triples braking with a two-axle tractor was better than a three-axle tractor. During the fast stops the trailers did not always stop in a straight line and would not always remain in its own lane.

While operating in heavy rain, the Triples with permanent spray retarders showed to have significantly less splash to spray than the other combinations (other large trucks) not so equipped.

Noise readings were made during the operation of the loaded Triple tests. These readings were taken both on flat terrain and on grades. The noise emissions were not unusually high or low when compared to other trucks.

ROCKY MOUNTAIN DOUBLES

The Rocky Mountain Doubles combination consisted of a three-axle conventional tractor pulling a 48-foot semitrailer and a 28-foot trailer. Essentially it was a long tractor-semitrailer plus a 28-foot trailer. This combination had an overall length of 93.2 feet and when loaded had a gross vehicle weight of 106,850 pounds.

The Rocky Mountain combination was the intermediate of the three tested combinations for maneuverability. As noted in the off-tracking tests and the travel through the same interchanges and intersections, the Rocky Mountain Doubles could not maneuver as well as the Triples, but could maneuver better than the Turnpike Doubles.

The Rocky Mountains had none of the problems experienced by the Triples on the open road, and actually proved very solid during these runs.

Even though the Rocky Mountain Doubles were the shortest and lightest of the three combinations tested, it was considerably longer and heavier than other large trucks. This was demonstrated on urban arterials where even this combination had difficulty making necessary lane changes. It was also demonstrated in the roadside rest areas and the truck weight scales where the Rocky Mountains exceeded the available lengths of the truck parking/inspection areas and also had some difficulty in maneuvering through these areas.

The weight of this combination was again noticeable on acceleration and speed on grades. With a lower weight/horsepower ratio, the Rocky Mountain Doubles did perform better than the Triples in these two areas however.

The weight again appeared to be offset by the increased axles and tires during the braking tests. The stopping distances were within the same range as today's semis and actually were marginally better than the Triples. Again, however, the Rocky Mountain Doubles did not always stop in a straight line.

TURNPIKE DOUBLES

The Turnpike Doubles were the least maneuverable of the three combinations tested. This was shown by the movements through interchanges and intersections and by the off-tracking tests. In fact, this combination had problems maneuvering through interchanges of the latest design in rural areas. On occasion, the Turnpike's inside rear tandems mounted the asphalt beam delineating the shoulder edge and ran off of the pavement while using all the space available on the ramp.

Like the Rocky Mountains, the Turnpike Doubles proved very stable on the open road.

This LCV, being the longest and heaviest of the three tested, exhibited all of the size features and impacts mentioned for the other two combinations. Portions of the speed on grade tests were compensated for by use of a more powerful 480 HP tractor. The use of various tractors throughout the test allows conclusions to be drawn on various weight and horsepower configurations for operation on grades.

Again, like the other two combinations, there was not a major difference between the stopping distance of the Turnpike Doubles and other long semis. The braking tests for this combination did, however, show the need for proper securing of the load.

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ACKNOWLEDGEMENTS

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Mr. Scot Bishop
Manager, Safety and Training
Viking Freight Systems, Inc.

and

Officer B. O. Norton
California Highway Patrol

Their long hours, technical knowledge, and willing assistance - all beyond the call of duty - allowed for the successful and safe completion of these tests.

LONG COMBINATION VEHICLES

OPERATIONAL TEST

INTRODUCTION

The Surface Transportation Assistance Act of 1982 (STAA) in Sections 138 and 415 mandates a study of longer combination commercial motor vehicles. Sections 138 and 415 state in part:

> "the Secretary of Transportation--shall submit to Congress a detailed report on the potential benefits and costs--of a national intercity truck route network for the operation of a special class of longer combination commercial motor vehicles."

In the Federal Register of April 25, 1983, the Federal Highway Administration (FHWA) announced the study approach and established a public docket for the Section 138/415 study. The Register further contains the following statements.

> "Implicit in the concept of a network for longer combination vehicles are several assumptions. One is that there is a network that can safely accommodate longer vehicles."

> "The scope of the study involves the identification of vehicles and their performance characteristics...".

"Longer combination vehicles means truck-tractor-semitrailer-full trailer (double) and truck-tractor-semitrailer-full trailer-full trailer (triple) combinations up to 110 feet with gross combination weights subject to the bridge formula and the single and tandem axle weight limits set forth in 23 U.S.C. 127."

The California Department of Transportation (Caltrans) has experience and capability in the on-the-road testing of large trucks stemming most recently from the system designation effort for the STAA-mandated "interstate" trucks. Except for a single eight-day, 1,500 mile on-the-road test of Triples in 1971, Caltrans had no experience with the longer combination vehicles (LCVs) defined in the Section 138/415 study.

Caltrans offered, and FHWA accepted the offer, to conduct on-the-road operational tests of various LCVs. This offer, besides allowing Caltrans to observe the operation firsthand, was made because California has all the diverse conditions through which LCVs could potentially operate. Although current LCV (e.g., Triple, Rocky Mountain) operation is generally operated under permit or restricted in operation, this LCV operational test did not apply those same restrictions. This test, in addition to showing the actual operational characteristics of each combination, also tried to show under what conditions the operation might be restricted and why it might be restricted. The

hypothesis was that LCVs could operate on the existing system and only the shortcomings of each combination should limit its use.

This report describes Caltrans' operational testing, observations and documentation of three combinations (Triple Trailer, Rocky Mountain Doubles, Turnpike Doubles) of LCVs in California. This report does not, nor is it intended to, comment on any other feature of the Section 138/415 study. Neither is it intended to comment on any other issues surrounding the trucking industry, such as tax equity, removal of the Formula B maximum weight, or any regulatory aspects.

GENERAL PROCEDURES

An Advisory Committee consisting of the California Highway Patrol (CHP), FHWA, and the Western Highway Institute (WHI) assisted Caltrans in outlining and generally scoping the operational tests to be conducted for the three LCVs. WHI is a nonprofit trade association that provides engineering, legal research and coordination services for the trucking industry in 13 Western states and Western Canada.

A Request for Proposal was sent to numerous trucking companies in the Western states asking for bids to supply the necessary equipment (tractors and trailers), an experienced driver, and the necessary permits for up to a two-month period. Viking Freight Systems, Inc., of Santa Clara, California, was the successful

bidder and supplied or arranged for all the necessary equipment and personnel. After several orientation meetings and necessary preparations for some of the tests, the actual Operational Test began on October 24, 1983. The test itinerary is attached as Appendix A.

Three combinations and two sub-combinations were actually run on the road. These were a Triple Trailer set (three 28-foot trailers) with both a cab-over-engine (COE) tractor and a conventional cab-behind-engine (Conv.) tractor; a Rocky Mountain set (one 48-foot semitrailer plus one 28-foot trailer) pulled by a conventional tractor; and a Turnpike Double set (two 48-foot trailers), also called Double 48's or 2x48, pulled at times by two different conventional tractors.

Each major combination was operated over essentially the same 1,200+ mile route, each combination being tested for one full week. This 1,200+ mile route (Fig. 1) allowed testing over a variety of topographical, meteorological, traffic, and roadway conditions. This routing provided the physical conditions, except snow and ice, that would be encountered in California if action were taken to allow their operation. Running each combination over essentially the same route allowed not only testing of each combination, but also allowed a direct comparison between the various combinations under the same or similar conditions.

TEST TRUCK ROUTE

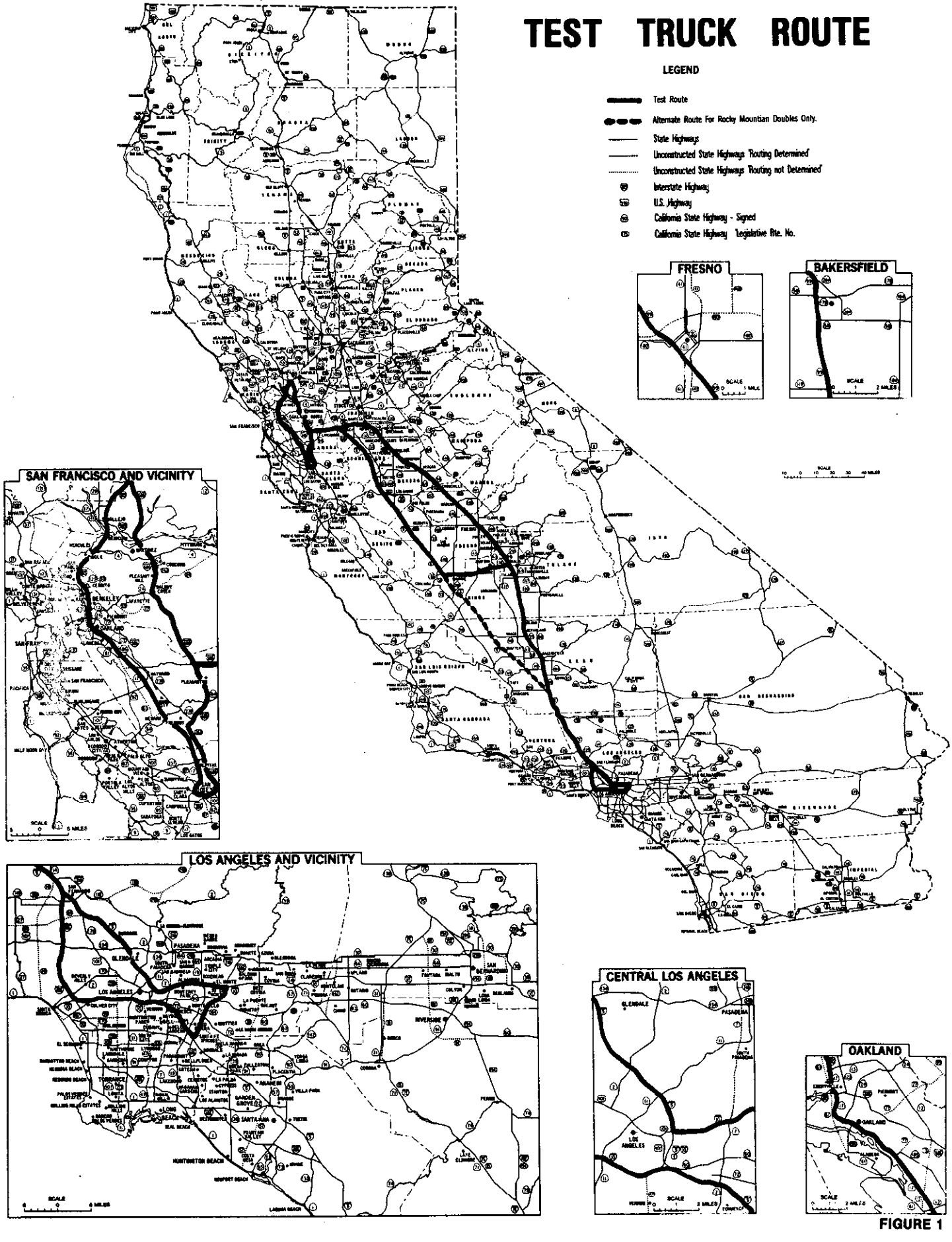


FIGURE 1

Where possible (e.g. speed, braking, off-tracking, etc.), actual measurements were made of the test results. Where physical measurements were not possible (e.g., open road, urban traffic, etc.), the test results are the observations of the test personnel or observers. All tests were filmed or voice recorded for documentation. Caltrans is producing a film on the full test.

The CHP was an integral part of the test team and provided a number of services. The CHP officer is a Mobile Road Enforcement officer trained to perform the Critical Item Inspection for commercial vehicles. Each combination was inspected daily to ensure safe operation during the tests. Generally, no safety problems were detected during the test.

The CHP officer also acted as an escort and provided traffic control services at times. The CHP, while escorting the test, made a concerted effort not to be visible. This allowed a more natural interaction between the test truck and the rest of the traffic. The intent was not to isolate the test vehicle from the conditions in which it would normally run. Generally, this was successfully accomplished.

The test attracted attention and at times various observers followed the test for some distance. WHI, as an original participant of the study and an interested research organization, observed all the testing and was available for technical assistance. Others, who observed a portion of the testing,

included the California Teamsters, the Automobile Club of Southern California, various truck equipment manufacturers, local and State law enforcement agencies, Caltrans employees, and local and national news media. Each of these observers was allowed close observation of the actual testing, but did not interfere with the actual conduct of the tests.

EQUIPMENT

As provided in the contract, Viking supplied all the tractors and trailers needed for the conduct of the operational test.

o Trailers

Six 28-foot by 102-inch van trailers were made available from Viking's fleet (VT 1540, VT 1554, VT 1581, VT 1595, VT 1603, VT 1611). These Great Dane trailers were essentially identical, having been ordered in the same batch, and were approximately six months old. They had been in actual service operation in Oregon as part of Viking's Triple Trailer service. Two unique features on these trailers were that they had bolt-on spray deflectors as required in Oregon Triples operation and they had automatic brake slack adjusters which were designed to keep the brakes adjusted automatically. Having six trailers (two separate Triple sets) available allowed testing of both empty and loaded Triples without having to load or unload them as a test phase went from empty to loaded or vice versa. This also

ensured that for loaded tests, each Triple combination was loaded exactly the same.

A number of single axle converter gears (dolly, congear) were made available from the existing Viking fleet. These were 96-inch width dollys (102-inch wide single axle dollys not being available) and generally also had the automatic slack adjusters.

Two 48-foot by 102-inch van trailers were made available from Doudell Trucking (#4812, 4818). These Great Dane trailers again were less than six months old and had been used in actual operation. These trailers had Fiberglass Reinforced Plywood (FRP) sides and nose. It was necessary to add a pintle hook and air brake connections to #4818 as a 48-foot trailer was not available with these features from any manufacturer. These add-ons created no problems, except that the additional framing for the pintle hook prevented sliding the rear tandem all the way to the rear of trailer No. 4818.

A 96-inch tandem axle dolly was used for the Turnkpike Doubles combination. This dolly was about five years old, and required all new tires and revised plumbing and valving to bring it up to the quality of the other equipment.

o Tractors

A total of four tractors were used during the Operational test.

Two Kenworth K-100 Cab-over-engine (COE) 4x2 tractors were made available from the existing Viking fleet. Both K-100's had a 120-inch wheelbase. The first K-100, HD 4176, was used on both the empty and loaded portions of the Triples tests. This tractor was more than three years old, had about 270,000 miles on it, had an automatic transmission with a transmission speed retarder, had disc brakes, was powered by a 8V92 Detroit diesel, and produced 304 horsepower (HP) to the ground at 2,000 RPM.

The second K-100 (HD 4205) was very similar to HD 4176 except that it had drum brakes instead of disc brakes. HD 4205 was only used for the Triples braking tests, and was used in place of HD 4176 to give more comparability to other braking tests which also used drum brake tractors.

These two tractors were the only ones with aerodynamic features on them. Both had air deflectors on top of the cab.

The third tractor was a Ford LTL 9,000 6x4 conventional tractor from the existing Viking fleet. This tractor, HX4272, was a 1983 model with about 90,000 miles on it. It produced 340 HP to the ground at 2,000 RPM (after modifications after the first week) and was powered by a 3406 Caterpillar diesel coupled with

a Fuller RT 910 10-speed manual transmission. It had a 186-inch wheelbase. HX4272 was used for some of the empty Triples test, all of the Rocky Mountain tests, and most of the Turnpike Doubles tests.

The fourth tractor (#BR1) was an almost new Freightliner with only about 9,000 miles on it. This 6x4 conventional tractor had a 210-inch wheelbase. It was powered by a Cummins NTCC-400 diesel, coupled with a Fuller RTO 913 13-speed manual transmission and produced 480 HP to the ground. This tractor was used only one day with the loaded Turnpike Doubles. That day's testing included runs over the Grapevine grade (sustained 6% grade), both north- and southbound, and the urban run in Los Angeles. The main reason for obtaining this high HP tractor was to see if a reasonable speed could be obtained over the Grapevine grade.

To test the representativeness of the two 3-axle tractors to available 3-axle tractors, the test tractors' lengths were compared to a sample taken for another research project. In a sample of 145 measurements, taken in both Northern and Southern California, the average distance between the first and third axle was 18.2 feet. This compares to the first to third axle spacing of 17.6 feet for HX4272 and 19.7 feet for BR1. Both test tractors could be said to be representative of today's fleet.

o Combinations

The actual measured lengths and recorded weights for each combination are shown on Figures 2 through 6.

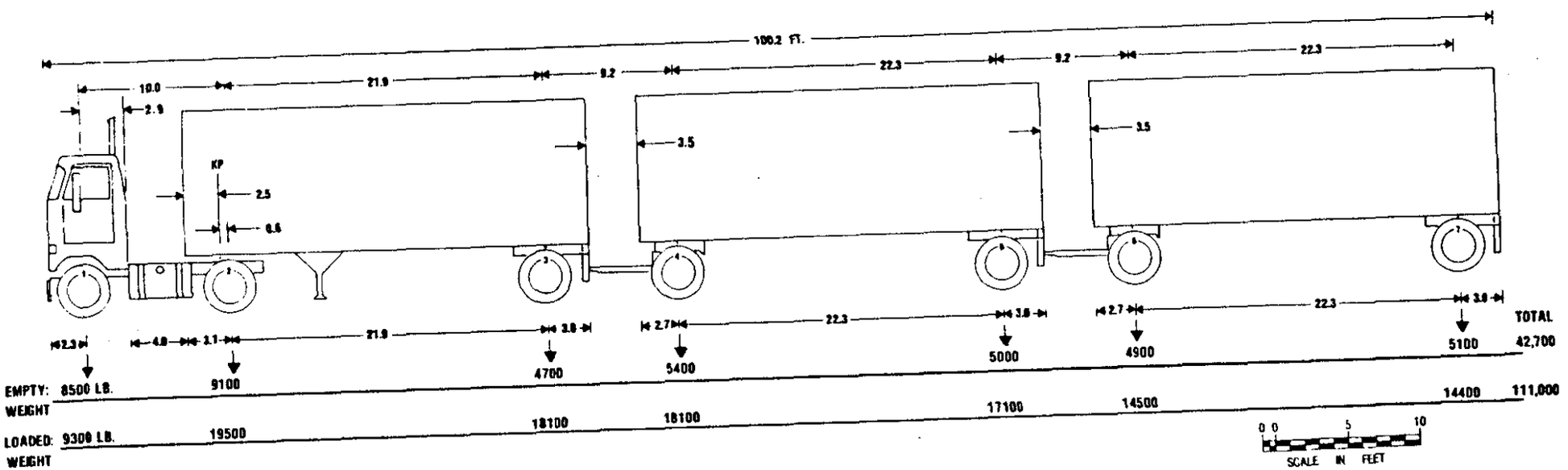
Each combination was loaded as heavily as possible without exceeding the Formula B limits. The 80,000 pound upper limit was not considered. The Triples were loaded to 111,000 pounds, and were within 100 pounds of Formula B maximum; the Rocky Mountains were loaded to 106,850 pounds, within 250 pounds of maximum; the Turnpike doubles were loaded to 122,650 pounds within 2,250 pounds of maximum. The actual Formula B calculations are shown in Appendix B.

The combinations were loaded in accordance with WHI recommendations. That is, the heaviest trailer was in front, the lightest trailer in the rear, and a balanced load in each trailer.

Generally, all equipment had "fast acting/quick release" braking equipment (minimal delay in application and release of the brakes along the length of the combination), as again recommended by WHI. Further, no-slack pintle hooks were used at all connections, again in accordance with WHI recommendations for Triple operation.

LONGER COMBINATION VEHICLE DIMENSIONS

TRIPLE TRAILERS (COE)



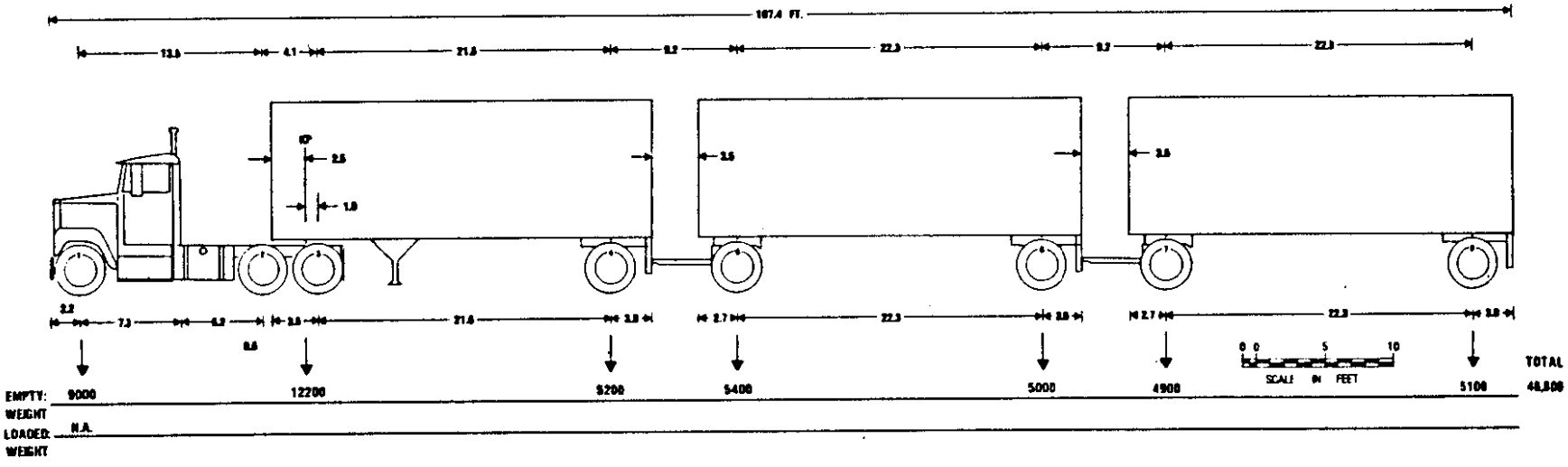
TRAILER COMBINATION: VT 1595,1554,1581 (EMPTY) / VT 1603,1540,1611 (LOADED)

TRUCK: HD 4176 / KENWORTH 4x2 COE

NOTES: 28'x102" GREAT DANE VANS,96" DOLLYS

FIGURE 2

LONGER COMBINATION VEHICLE DIMENSIONS
TRIPLE TRAILERS (CONVENTIONAL)



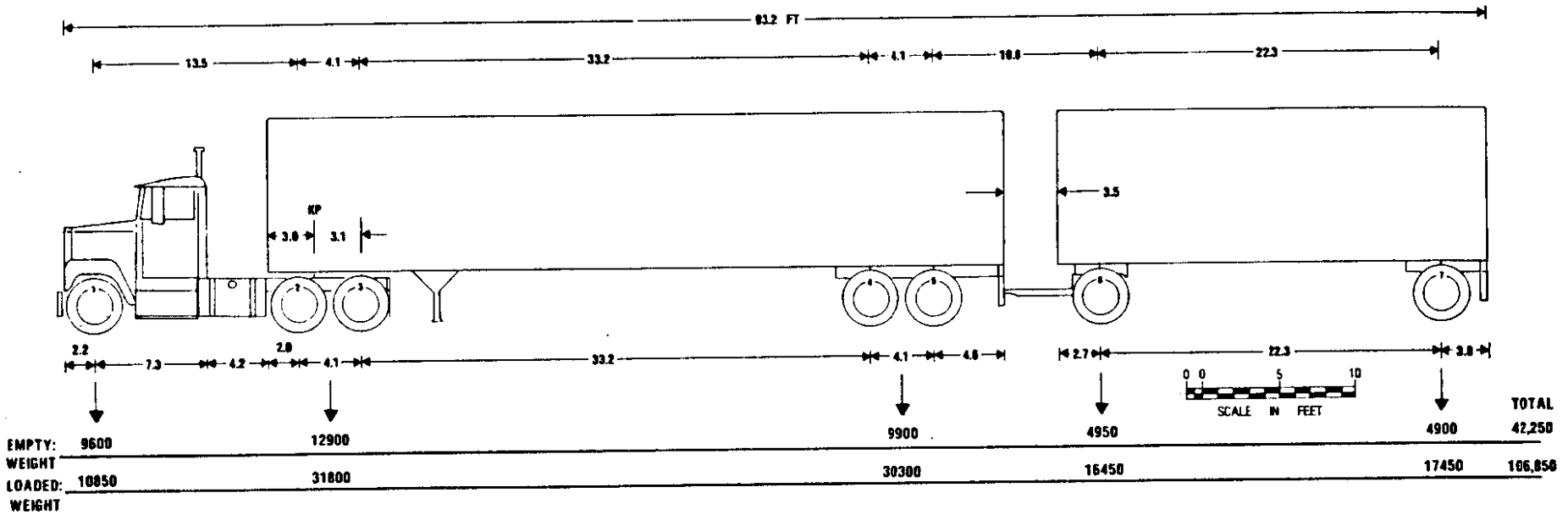
TRAILER COMBINATION : VT 1595,1554,1581

TRUCK : HX 4272
FORD LTL 6x4 CONVENTIONAL

NOTES : 28'x102" GREAT DANE VANS,96"DOLLYS

FIGURE 3

LONGER COMBINATION VEHICLE DIMENSIONS
ROCKY MOUNTAIN DOUBLES



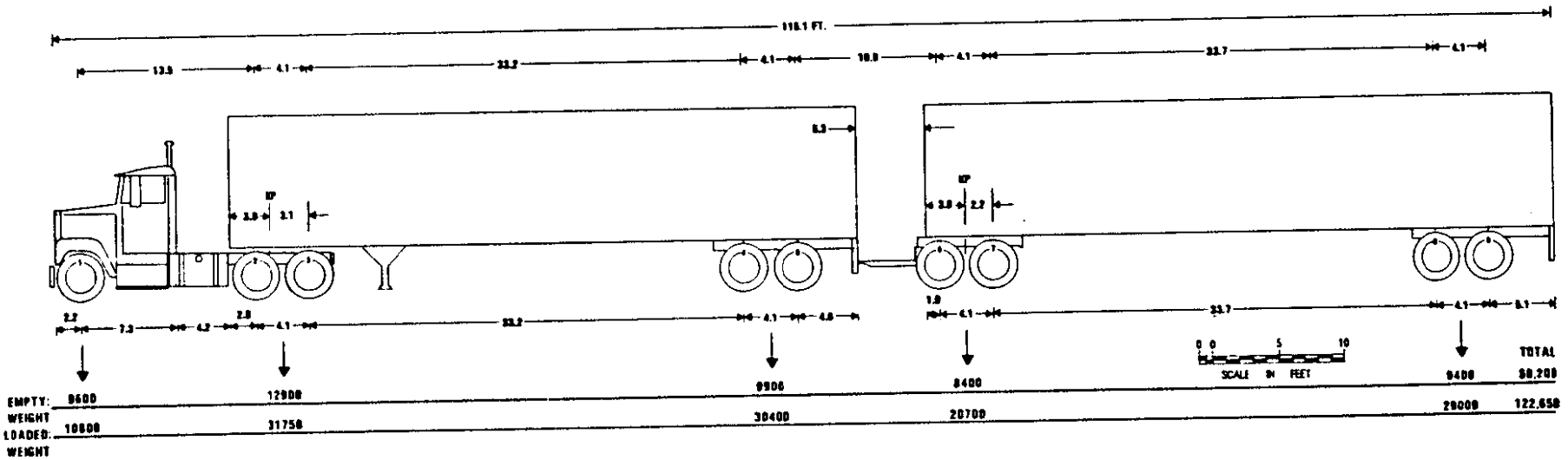
TRAILER COMBINATION : 4818,VT 1581 (EMPTY) / 4818,VT 1540 (LOADED)

TRUCK : HX 4272 / FORD LTL 6x4 CONVENTIONAL

NOTES : 48'x102" & 28'x102" GREAT DANE VANS,96" DOLLY

FIGURE 4

LONGER COMBINATION VEHICLE DIMENSIONS
TURNPIKE DOUBLES (HX 4272)



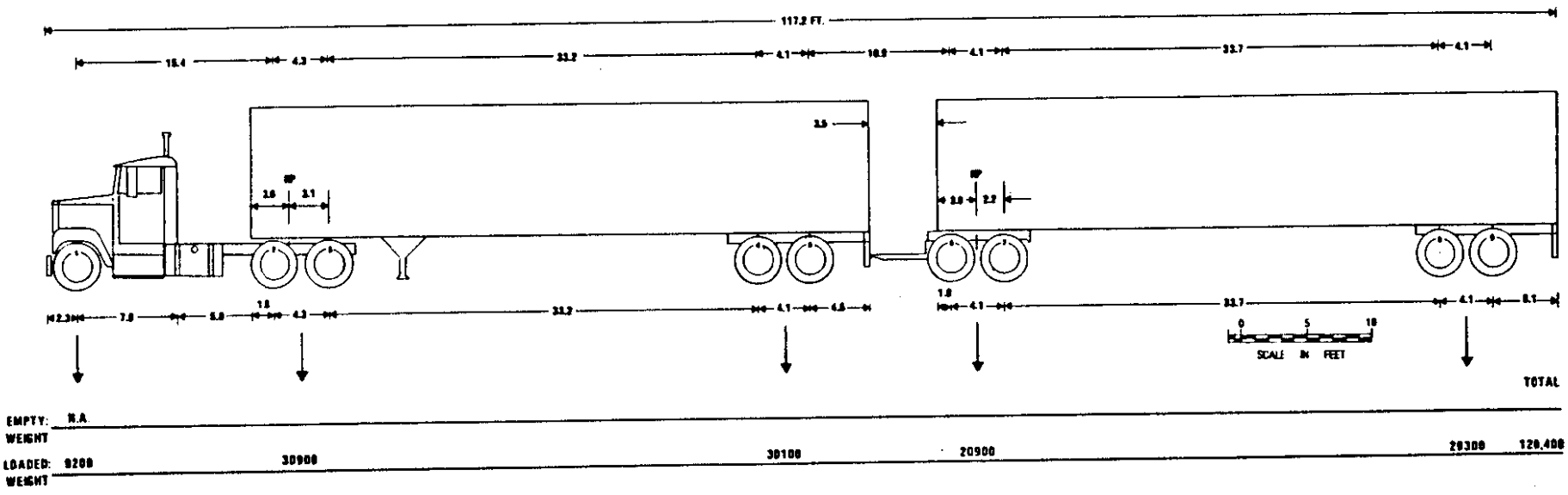
TRAILER COMBINATION: 4818,4812

TRUCK: HX 4272
FORD LTL 6x4 CONVENTIONAL

NOTES: 2-48'x102" GREAT DANE VANS,96" LUFKIN DUAL AXLE DOLLY

FIGURE 5

LONGER COMBINATION VEHICLE DIMENSIONS
TURNPIKE DOUBLES (BR 1)



TRAILER COMBINATION: 4818,4812

TRUCK: BIG RED ONE
FREIGHTLINER 6x4 CONVENTIONAL

NOTES: WEIGHTS AT WHEELER RIDGE SCALES,2-48'x102" GREAT DANE VANS 96" LUFKIN DOLLY

FIGURE 6

o Driver

One Viking driver did all the driving during the tests. He is one of Viking's line haul drivers assigned out of Sacramento. He has 25 years experience driving commercial vehicles, about 22 years driving 40-foot semis and doubles, and has been with Viking for 10 years. He has also completed Greyhound Bus Company's driver training program. He has driven commercially in 26 states and Canada, mainly in the west, and has had over a year's experience driving Triples in Oregon. About 20 years ago he had his only commercial accident, which, though avoidable, was non-chargeable to him.

o Summary

All equipment and the driver used in these tests were of a high quality. There were no special modifications or unique test conditions, however, to put these qualities out of reach of today's fleets and drivers. The test driver and most of the equipment have been used in some Triples operation in other states.

Caltrans views these tests as demonstrating a threshold capability for each combination. Each combination is capable of operating at the level indicated in these tests and any shortcomings exhibited during the tests are inherent to that combination. Some of these shortcomings may be mitigated by more restrictive

limits of operation (e.g., permits). Argument can be made that in actual day-to-day operation these combinations will not operate up to these thresholds because the equipment gets older, wears out, or is not maintained in its new state.

While the equipment used is representative of that on the road today, it does not measure up to the extremes that could be used. For example, there are a large number of COE tractors in the San Francisco Bay Area with a front axle to rear axle length of 23.0 feet (as opposed to 19.7 for conventional BR1, the longest used in these tests), and an overall length of 27.7 feet. These longer tractors can legally pull both 48-foot semis and 28-foot doubles today, and potentially are capable of pulling the combinations tested. This longer length would have adverse impacts in certain handling and tracking features, and must be considered when decisions are made as to the feasibility of or restrictions on the operation of LCVs.

TEST RESULTS

o Freeway Interchanges

All combinations were run through generally the same set of freeway/freeway and freeway/local road interchanges to 1) observe how each combination performed and 2) allow for a direct comparison between the combinations. A full listing of all interchanges traversed is attached as Appendix C.

The Triples generally had no problems on the ramps and could maneuver almost as well as a long tractor semitrailer (48 ft. trailer, practical 43 ft. kingpin-rear axle length) which is limited to the Designated System. The Rocky Mountain Doubles (RMs) started to encounter problems in maneuvering through some interchanges. The Turnpike Doubles (2x48) encountered significant problems on most interchanges.

Both the RM and the 2x48 consistently placed all four tires of the right rear set of duals onto the paved shoulders of loop ramps. There were two instances where the right rear duals actually crossed over an asphalt berm delineating the outside of the shoulder on the loop ramps. Both occurred with the 2x48 when it was already using as much room as the loop ramp allowed. Such actions would result in accelerated deterioration of shoulder edges and increase the chances of striking roadside objects.

I-5 in the Central Valley is the last major new route built in California in a new location. At the time of construction, there was no development along the route which limited the size of or room needed for interchanges. The 2x48 exited I-5 in this reach at numerous locations where services might be available, using both diamond and loop ramp interchanges. In each instance, the 2x48 either used all of the room (lane plus shoulder) available or exceeded it. The extreme example occurred at Santa Nella, a major truck stop area at the junction

of I-5/Route 33 that has been approved as a service access location to the Designated System. The westbound to southbound move involves a 2-lane road (Route 33), a loop ramp through 120-135°, and entering I-5 southbound. In this case, the 2x48 crossed into the opposing traffic lane on Route 33 before entering the loop ramp, used all the space available for the loop ramp, and still placed the right rear duals on top of the asphalt berm outside the shoulder.

Many of the older design interchanges still on the Designated System, rather than having the ramp roadway and shoulder on one plane, actually have a concrete gutter and rolled curb delineating the ramp from its shoulder. Both the RM and 2x48 consistently crossed over and climbed this rolled curb. Where this occurred, it was not unusual for only one tire of each rear dual to be riding on top of the curb (a 1-2 inch width) with the other dual tire being suspended in the air. This situation would create significant pressure (essentially 1/4 of the trailer weight over a few square inches) on both the tires and the curbs. This would create the potential for very rapid curb deterioration and/or tire blowout.

Based on the ramp movements observed, there is a significant difference between each of the combinations. The Triple Trailers could handle most of the interchanges traversed reasonably well; the RM could handle most of the interchanges using almost all of the room available; the 2x48 had significant

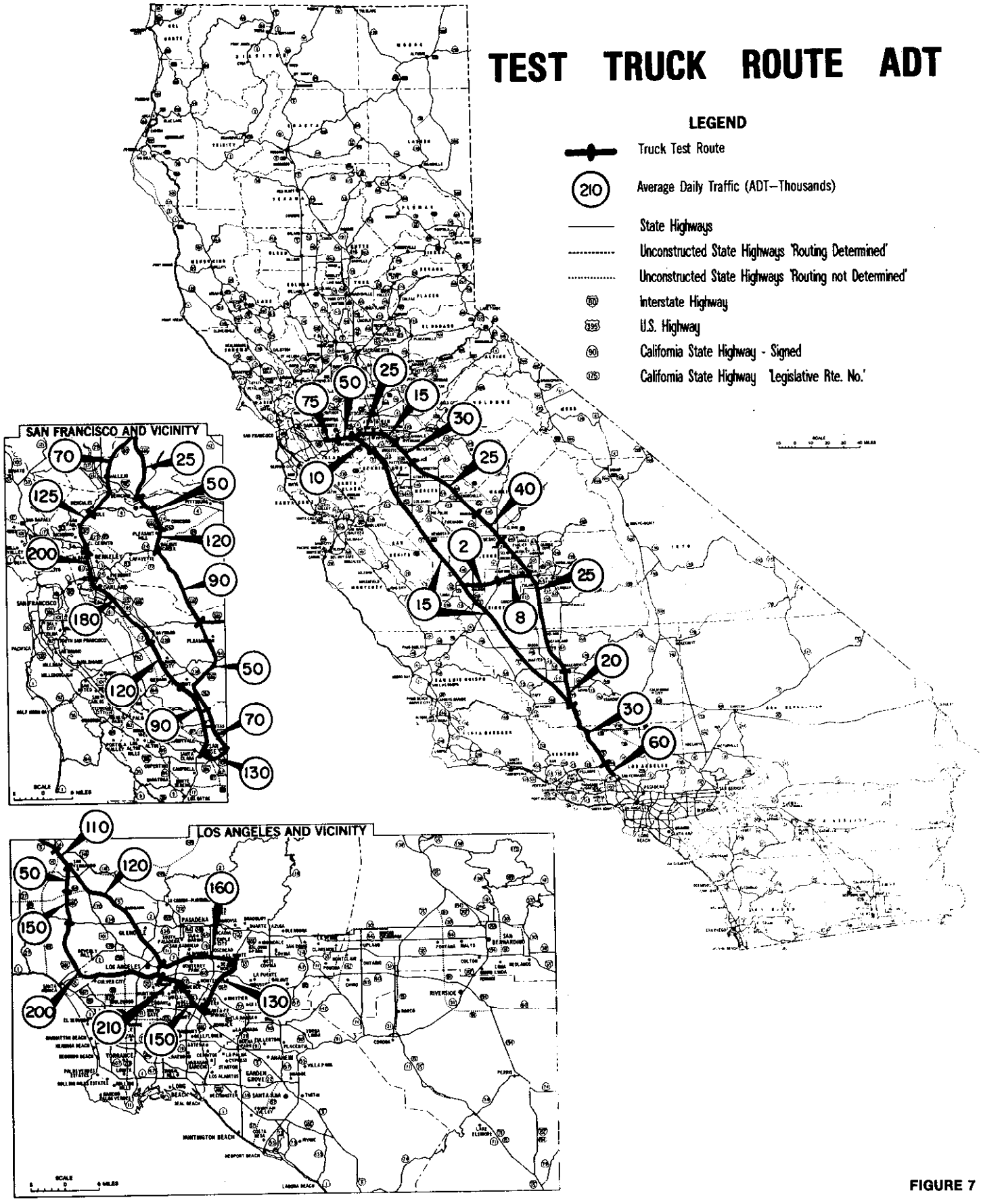
problems on existing interchanges and would require either substantial pavement edge maintenance work or new facilities with design standards far exceeding those existing today.

o Open Road

This test was conducted to see how the combinations would operate on an open road section with only minimal interference from other traffic. These runs were made on rural or semi-urban freeways and probably will constitute the majority of the facilities driven by LCVs. These runs were made with the combination both empty and loaded.

The average daily traffic (ADT) for I-5, the least traveled of segment travelled on the test, averages over 15,000 vehicles per day. The attached ADT map (Fig. 7) shows the range of traffic to which the combinations were exposed. While it cannot be fully verified, existing data (Motor Vehicle Size and Weight Standards, the TRED Foundation, July 1980, p. 125) suggests that California's rural routes have significantly (more than 50%) more traffic than other Western States. In 1982, the average ADT nationally for all rural Interstate routes was about 11,800.

The Viking driver was told to drive as he normally would, as if this were not a test. All level open road segments were run at 55 to 60 mph.


TEST TRUCK ROUTE ADT
LEGEND
Truck Test Route
210 Average Daily Traffic (ADT—Thousands)
State Highways
Unconstructed State Highways 'Routing Determined'
Unconstructed State Highways 'Routing not Determined'
80 Interstate Highway
395 U.S. Highway
90 California State Highway - Signed
175 California State Highway 'Legislative Rte. No.'
SAN FRANCISCO AND VICINITY
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LOS ANGELES AND VICINITY
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2
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8
20
30
60

FIGURE 7

Portions of the Open Road test, as well as the Urban Traffic and Freeway Interchange tests, were conducted after dusk. In each of these tests there were no significant differences with the daylight operations.

Triples

The operation of Triple Trailers over the open road segments created one of the major reactions of the test crew and observers. There were extended periods of a constant "whip and sway" of the Triples during this phase of the tests. This corresponds almost exactly to the observation recorded in the 1,500-mile open road test of Triple Trailers conducted by Caltrans in 1971.

The same set of Triple Trailers were pulled by both HD4176 (two axle COE) and HX4272 (three axle conv.) to see if there was any perceivable difference in operation using two different types of tractors. No difference could be detected. There was also no noticeable difference in the open road operation when loaded or empty.

The sway encountered consisted of a constant four- to six-inch total displacement sideways movement of the interior (mid-length) portion of the trailer combination. The trailer combination had a sine wave or serpentine appearance with the maximum deviation appearing to occur between the second and third trailers. There was generally little apparent sideways

movement of the rear of the third (rear) trailer, rather the movement was limited to the interior of the combination. During periods of no sway, the combination tracked straight with no deviation being seen. This generalized observation applied to two separate combinations of Triples; the empty Triples used three different trailers than the loaded Triples.

The serpentine action was particularly noticed on I-580 (from I-205 to I-5) and I-5 (from I-580 to Route 198). This 125-mile segment consists of a modern design standard, four-lane freeway in rolling and flat terrain in totally rural areas. There was no noticeable wind, minimal traffic, and no apparent physical deficiencies of the facility. The Triple Trailers, however, were in a constant serpentine motion for this entire segment.

While the Triples generally operated with the four- to six-inch serpentine action, this is not a total observation. There were times when there was no sway movement of the trailers. There were other times, however, when the motion approached the 8-10-12-inch range for significant periods of time. There were also isolated incidents when the sway greatly exceeded one foot and approached the two- to three-foot range. It is estimated that some sway occurred for over 75 percent of the total mileage operated by the Triple Trailers. This situation appeared in the 1971 tests and it has not yet been resolved, at least with off-the-shelf equipment.

There was considerable speculation among the test team and observers on the reasons for the sway and what could be done to eliminate it. Almost a dozen reasons have been mentioned, but none could be ruled out totally, and none could be identified as the single major reason. Additional research on this phenomenon was not within the scope of this test, but Caltrans feels it would be appropriate for some research agency to investigate it more fully.

Rocky Mountain Doubles

The RM can be best described by repeating a radio transmission by the test crew--"they (the two trailers) look like they are welded together." There was absolutely no whip or sway observed by the test team during the open road testing of the RM doubles.

On long, high speed, sweeping freeway curves, the rear trailer would straighten out in the curve. Rather than tracking in a circular pattern around the curve, the rear trailer would periodically (a few times around the curve) attempt to form a straight line with the lead trailer. This "straight-lining" would result in a 1- to 2-inch movement of the rear of the rear trailer each time. This is not considered a problem.

Turnpike Doubles

The 2x48 had the same operating characteristics as the RM, including the curve "straight-lining". No open road problems were observed with this combination.

o Urban Traffic

All three combinations were run through significant amounts of urban travel conditions to see how the LCVs would operate in urban areas.

This test had four elements to it:

- o how well the combinations operated on urban freeways.
- o the impact they had on urban ramp traffic entering or leaving the freeway.
- o how well they operated on urban arterials.
- o how well they operated in urban arterial intersections.

Urban Freeways

All three combinations experienced typical urban freeway operation including stop-and-go and slow-and-go conditions, lane drops, and freeway merges.

The major observation of the test team is that the viability of LCVs on mainline urban freeways depends much more on the skill of the driver than the length or configuration of the combination tested. The driver took the approach of driving a steady line; that is, an absolute minimum number of lane changes, making the necessary lane changes far in advance, trying to maintain a constant speed, and not rushing through the urban areas. This gave the auto drivers a constant, or at least predictable, truck that they could react to when making their decisions.

The driver had no problem maintaining the speed of the rest of the traffic, but left himself more room in front than observed being done by other trucks and autos. This did give others a chance to make lane changes.

There were a few selected instances where a vehicle was alongside the test truck when lane drops occurred. This generally required quick action (acceleration or braking) on the part of the other vehicle. This same situation, although less severe, also occurred with other trucks or even autos.

All in all, the driver had no significant problems in urban freeway traffic, even in stop-and-go conditions. As stated initially, this is primarily a credit to the driver. Viking management claims this type of driving is "expected of professional drivers".

Urban Ramps

The larger combinations had only a minimal impact on vehicles wishing to enter or exit the urban freeway. This is due primarily to the driver, where possible, driving one lane over from the right lane. Route 17 south of Oakland is a heavy truck route, and this one-lane-over technique was practiced by all of the trucks.

There were situations where this technique was not possible (e.g., 2-lane one-way) and it was noted that entering vehicles did not always have an open space into which to merge, requiring either a braking or acceleration (or occasionally driving on the shoulder) action. This action under the same traffic conditions was observed where interference was created by autos, other trucks, or the test truck. The amount of interference appears to be proportional to the vehicle length.

The test vehicle had no major problem entering or exiting the freeway due to interference from main line traffic. Again, this is due to the driver taking appropriate needed action earlier than generally taken by most auto drivers.

Urban Arterials

The traffic on the urban arterials during the test ranged from moderate congestion (Level of Service "B" or "C") to stop-and-

go traffic. In the moderate congestion, the driver had no problems either maintaining speed or performing the necessary lane changes. This, again, was based on the driver taking early appropriate action.

As congestion increased, problems on the arterials became more severe than on the freeways. For a given level of congestion, the speeds are slower on arterials than on freeways; assuming a constant time headway, this results in less headway distance between vehicles on arterials than freeways. Arterials also have signals creating packs of traffic rather than spreading out the traffic (and headway) as occurs on freeways. These two conditions allowed significantly less opportunity for the driver of the test vehicle to make necessary movements on congested arterials. While there was no perceiveable difference in these movements between the three combinations, each combination had significantly more problems than other observed shorter trucks or transit buses.

The 2x48, and to some extent the RM, also had some difficulty in entering/exiting Viking yards on arterials. In Modesto, the Viking facility is on Crows Landing Road, a 4-lane arterial with a striped dual left-turn lane, and has a curbed 30-foot wide entrance and exit. On a right-turn exit from this yard, the 2x48 actually encroached about four feet into the dual left-turn lane. This move required stopping the traffic on Crows Landing Road at 11:00 AM so the truck could make the move. It is

doubtful that the 2x48 could make this move safely without substantial waiting for a traffic opening.

Urban Intersections

The situations experienced with urban intersections depended upon which combination was used and the room available in the intersections. This observation was verified by the off-tracking tests described later. A list of all intersections traversed is attached as Appendix D.

Generally, the Triple Trailers had the least problems, being able to maneuver almost as well as a long tractor semitrailer. The RM was less maneuverable than a 48-foot semi and the 2x48 at times had significant problems. At no time, however, was there a need to break-up and back-up any of the combinations while making the run.

In each case, there was some encroachment into adjacent lanes, both into and out of the turn, for each combination. This ranged from about 2-feet each (into and out of the intersection) for the Triples, to approximately 4-feet each for the RM, to the full lane each for the 2x48. If encroachment room was not available for either the entrance or exit, that much additional room was needed for the other half of the movement. This encroachment could result in delay to either the truck or other traffic until sufficient room to make the move became available;

sufficient room to make the move became available; additional potential damage to curbs or roadside signs and signals at intersections (the test team observed neither); or traffic being caught between the truck and other fixed objects (this was observed once with a pickup in a free right turn lane).

Left turns, where left turn pockets were available, were not made from the pockets. The reasons were that 1) the left turn pockets encountered were not long enough for the test vehicle to get into straight, 2) there was always someone already in the pocket to trigger the signal and also remove even more room from the pocket, and 3) the driver generally needed all the room he had available.

This situation could result in traffic getting trapped in the left turn lane (not observed); delay to straight through traffic behind the LCV or delay to cross traffic waiting for the combination to clear the intersection after the left turn signal had turned red (some observations); or again, increased damage to curbs, signals, signs, etc. (not observed during test).

The test team finally took the tactic of momentarily closing off non-signalized intersections to opposing traffic until the test vehicle had cleared it. While this tactic was not needed because of maneuverability, it was needed because there generally was not a sufficient gap in traffic from the three opposing directions to allow the driver to turn through the intersection.

While California is a Right Turn on Red (RTOR) state, this lack of gap condition prevented the driver from making such a maneuver during the test.

o Narrow Lanes

On part of each combination's run, lane widths which were less than 12 feet were encountered. About 24 mainline test miles of Interstate routes in the Los Angeles urban area have lane widths of 11 ft.-11.5 ft. Both the Triples and the 2x48 ran this route; it was felt the RM would show characteristics between these two extremes. There is also about 1000 feet on the northern end of the northbound Benicia Bridge (I-680) which has 3 lanes in a 30-foot width, an average of 10 feet per lane. This was run by all three combinations, and twice by the Triples.

With one exception, at no time did the test vehicle have any problems staying totally within its lane, not touching the raised pavement markers either right or left. The one exception was the second Triple run on the 10-foot lanes on the Benicia Bridge. In this case, the truck had the outside tire of the left side duals riding the lane line for about 1/3 to 1/2 of the 1000-foot section. This was the side away from the bridge rail on the right.

o Two Lane Roads

In the route from the Bay Area to Los Angeles, the Triple and 2x48 combinations were routed over Route 198 between I-5 and Route 99. This route is about 48 miles long, with the first 20 miles being a 26-foot and 32-foot wide 2-lane road, followed by about 18 miles of 4-lane divided freeway or expressway, ending with about 10 miles of 34-36 foot wide 2-lane road. The first 2-lane section has less than 2000 ADT, the freeway section has about 6000-9000 ADT, and the last section has about 7000 ADT. This route is on the STAA "Designated Network". The entire route is essentially straight and level with few at grade crossings.

While on Route 198, several passing maneuvers were made on the first section. The 2x48 was comfortably passed by other non-test vehicles and by the aft film van filming the passing maneuver. All these passing maneuvers occurred in the 2000 ADT section. There were not sufficient gaps in the 2-lane 7000 ADT section to attempt any passing.

Oncoming traffic tended to shy away from the centerline for not only the test truck but for any large truck. It was not unusual to see both the test truck and opposing traffic each having their right wheels on the shoulder delineation stripe. There was no observed difference between the test combinations and any other truck.

Route 198 runs primarily through agricultural land and has mainly dirt shoulders. There was some blowing dust observed when the test truck passed but, again, this was not substantially different from that observed for any other large truck. Neither interfered with following traffic. The amount of dust produced appears to be more a function of the amount and proximity of dirt shoulders than the the size of the truck.

o Freeway Facilities

LCVs could potentially make use of other facilities on or adjacent to the freeways. These facilities include Safety Roadside Rest Areas, truck scales, and truck stops.

Safety Roadside Rest Areas

Each test vehicle stopped at roadside rests along the route, all of modern design. Each roadside rest had separate parking areas for autos, and trucks, travel trailers, etc. The truck areas have diagonal parking with entrance "driveways" behind and exit "driveways" in front of the actual parking spaces. Thus, any truck would use the entrance driveway, park diagonally, and continue forward to use the exit driveway.

Except once, the test truck used from 3-5 truck spaces, parking diagonally across the diagonal spaces. The diagonal parking across the marked spaces was needed to prevent blocking the

entrance and exit driveways. The one exception was when the COE Triple tried to use only one designated space. The COE Triple was longer than the parking space and this effectively blocked the exit driveway for others wanting to leave. Depending upon where LCVs parked in the roadside rests, they could effectively prevent any following trucks from being able to utilize the SRRA. Because of the vehicle length, there would need to be some modification of California's roadside rests if LCVs were allowed into them. These modifications could range from simply restriping the truck parking area to some new construction or new areas solely for LCVs. The modifications necessary would depend upon the specific rest area configuration and the volume of LCVs using it.

Scales

All loaded trucks are required to stop at the truck scales. Where the procedure was to simply pass over the scales and continue back onto the freeway, there were no problems observed. However, occasions exist when a more detailed inspection (e.g., equipment check, overweight, etc.) would require other maneuvers in the scale areas, such as going under the inspection sheds or looping around the scales for re-weighing.

The test trucks had mixed success in demonstrating these additional maneuvers, depending upon the combination and the layout of the scales. At certain scales the maneuvers were not

even attempted because there was insufficient room to accomplish them. Generally, the newer larger scale facilities, such as Wheeler Ridge, posed no problems, although certain combinations (e.g., Triples) were more maneuverable than others (e.g., 2x48). The older facilities with less room, such as Castaic, however, did not have enough room for the 2x48 to perform all the potentially necessary maneuvers. In no case did any combination totally fit under the inspection sheds, potentially requiring the inspectors to work in adverse weather. Again, any modifications needed to accommodate LCVs would be site specific and would depend upon the volume of LCVs using the scales. On the surface, however, the scale modifications (where needed) would be much more substantial than changes to the rest areas.

Truck Stops

While truck stops are private facilities, they probably would be used by LCVs. Several times the test vehicles did have minor problems in finding a suitable parking space because of crowded conditions, its size, and its manueverability. In two cases, the driver parked in the driveways, and once had to wait for other trucks to move before he could maneuver into a space. Depending upon the number of LCVs, the truck stop owners may want to make special provisions for them.

Other

While running in the Los Angeles urban area, it was necessary for the convoy (film vans plus Triples) to make an unscheduled stop due to a problem not associated with the truck. While the convoy did find an extra wide shoulder location along the Santa Ana Freeway (I-5), this was the only possible spot available for many miles where a stop could have been made comfortably or easily. It would not have been feasible to exit the freeway.

There may be situations where emergency stops are required. Because of the LCVs length and maneuverability, there are significantly less opportunities to make such a stop in the urban area.

o Off-Tracking

Off-tracking is defined as the additional width (over and above the truck width) required by a vehicle when making a turn. In this case, the total width (or swept width) required when making a turn is the 102 inch width of the trailer plus the amount of off-tracking.

The off-tracking tests were conducted in Viking's Santa Clara yard. A Caltrans survey crew laid out 60, 80, and 100-foot radius curves over a 180° central angle on the parking lot surface. Central angle increments of 30° were marked on the

curves. Each test combination entered each curve on the tangent, placed the outside edge of his left front tire on the curve, proceeded to drive around the curve to the right, and exited the curve on the tangent. While driving around the curve, the inside edge of the right rearmost tire was continously marked on the pavement. The distance from the appropriate curve center to the rearmost tire mark was recorded at 30° increments, and the difference between this recording and the curve radius was measured as the amount of swept width.

For comparison purposes, a 48-foot semi with a 40.3 foot king pin to rear axle length, using a conventional tractor (HX4272), was also recorded. The Triples were recorded using both COE (HD4176) and conventional (HX4272) tractors. The results are shown on Fig. 8.

The off-tracking was generally at a maximum at around 120° of central angle. The off-tracking for each combination decreased as the curve radius increased. The off-tracking did increase as the combinations went from 48-ft. semi, to COE Triple, to conventional Triple, to RM, to 2x48. These measurements agree with the over-the-road observations made of the different combinations at the same locations.

OFF-TRACKING TEST
SWEPT WIDTH DISTANCE (FT.)

CENTRAL ANGLE AHEAD OF BC	48' SEMI	TRIPLE WITH COE	TRIPLE WITH CONV.	ROCKY MOUNTAIN	TURNPIKE	48' SEMI AT 50' RADIUS
60 FT. RADIUS						
0°	12.1	12.7	14.4	15.1	17.9	13.5
30°	18.4	19.7	21.1	22.5	28.2	20.1
60°	21.5	23.1	24.3	26.5	34.8	23.8
90°	23.5	24.7	26.0	28.7	38.8	26.2
120°	24.4	25.3	26.6	30.1	40.3	27.9
150°	25.0	24.4	25.3	28.9	38.4	27.8
180°	21.3	18.7	19.5	23.6	31.4	24.0
80 FT. RADIUS						
0°	10.7	11.0	12.6	12.5	14.4	
30°	16.1	17.1	17.8	19.1	23.0	
60°	18.2	19.0	19.7	21.4	27.1	
90°	19.1	19.7	20.2	22.7	29.1	
120°	19.6	19.8	20.5	23.4	30.4	
150°	19.8	19.4	20.1	22.7	29.4	
180°	16.2	14.3	15.1	16.8	20.4	
100 FT. RADIUS						
0°	11.6	11.6	12.2	12.2	14.4	
30°	15.6	16.0	16.5	18.0	21.5	
60°	16.6	16.8	17.3	19.3	24.0	
90°	17.0	17.1	17.7	19.5	24.9	
120°	16.9	17.1	17.7	19.7	25.4	
150°	17.3	17.0	17.6	19.8	25.3	
180°	13.7	13.1	13.2	16.4	19.1	

NOTE:

Measurement is distance from outside of radius curve to track of right rearmost wheel measured at each central angle. Measurement includes width of rear axle, 102" (8.5 feet) in all cases.

The 48 ft. semi had a king pin to rear axle distance of 40.3 ft.

Figure 8

o Grades

Speed measurements were made on various grades of the test trucks' hill climbing ability. The measurements were made at Altamont Pass eastbound and westbound on I-580, a sustained 4% and 3% grade respectively, and the Grapevine, northbound and southbound on I-5, both sustained 6% grades. Radar readings allowed simultaneous clocking of a large sample of 5-axle trucks against which the test trucks' speeds could be compared. The test trucks were fully loaded in these runs. Figure 9 summarizes the results of these recordings.

The slow speed, coupled with the number of trucks going over the Grapevine, required the test trucks (and other very slow trucks) to effectively use up one full lane in their immediate vicinity. The normal operation of the Grapevine consists of trucks using the right two lanes, the left of which is used by passing trucks, and the left two lanes being used by autos, the left of which is used by passing autos. During the tests, and especially with the loaded triples, the two truck lanes shifted from the right two lanes to the center two lanes. This was necessitated by other "slow" trucks needing a lane to pass the test trucks, and faster, passing trucks needing a lane to pass "slow" trucks. This would result, at times, with three lanes being occupied with side-by-side trucks and leaving only one lane open for autos. This was not observed at Altamont because the number of trucks was significantly less.

GRADE SPEED TESTS

(All Test Truck Combinations Loaded)

LOCATION	TEST TRUCK COMBINATION	TEST TRUCK SPEED	5-AXLE TRUCKS NUMBER OF OBSERVATIONS	5-AXLE TRUCKS RANGE	5-AXLE TRUCKS MEAN	TEST TRUCK PERCENTILE (1)
Altamont EB 4%	Triple	20 MPH	555	18-62 MPH	42.7 MPH	0.5
	RM	27				6.5
	2x48	24				3.6
Grapevine SB 6%	Triple	15 MPH	389	12-58 MPH	28.4 MPH	2.3
	RM	19				16.2
	2x48(3)	21				26.2
Grapevine NB 6% (2)	Triple	14 MPH	457	13-64 MPH	35.2 MPH	0.9
	2x48(3)	21				12.3
Altamont WB 3%	Triple	28 MPH	295	22-66 MPH	46.4 MPH	4.1
	RM	31				10.9
	2x48	27				3.7

NOTES:

(1) Test truck's speed as the percentile of the observed 5-axle truck speeds.
(2) The RM did not make this run.
(3) Using BR1.

Figure 9

This condition argues that some method be established to ensure a reasonable speed be maintained on the grades. Two potential methods exist. The first would be to simply establish a minimum legal speed, say 20 MPH. Enforcement of this method would be straightforward and the selection of equipment to accomplish this would be left to the individual operator. The other method would be to establish a minimum weight/horsepower ratio for all LCVs. The BRl 2x48 at about 250 lbs/HP achieved a reasonable speed relative to other trucks; the COE Triples at over 350 lbs/HP did not achieve a reasonable speed.

Observations were also made going down the 6% Grapevine grades. With both the 2x48 and Triples, there was considerable smoking of the brakes, more so on the Triples than the 2x48. There was never a loss of brakes. With the 2x48, the smoking brakes were limited to the dual axle dolly between the trailers. Although there were no mechanical defects found in the dolly, it was speculated that the smoking was caused by more aggressive brake lining. It is also possible the dolly had not applied as much braking force before, resulting in glazed lining which could cause the observed smoking.

Later measurement of the Triples determined that there was an uneven brake pressure being applied to the different axles, with very limited braking being applied at the dollys. There was also a brake pressure drop between connections: a 6-lb pressure drop between the tractor and the first trailer, 10 lbs

between the first and second trailers, and 12 lbs between the second and third trailers. Thus, there was little braking effort at the dollys and decreasing trailer brake pressure to the rear of the combination. This resulted in some brakes providing little stopping effort and others supplying more than their share. During this run, the Triples did not have the "fast acting/quick release" brakes. This was corrected with the dollys and 28-foot trailers being replumbed and revalved to obtain a proper balance before the braking tests were conducted.

o Braking

Braking tests were conducted on a partially constructed, unopened, section of new freeway in the Bay Area. All tests were conducted on the same roadway section and were run both empty and loaded, on wet and dry pavement. The combinations tested were described earlier and were the same combinations (and weights) used on the over-the-road tests. The wet pavement was obtained by a construction water truck applying a full width spray immediately in front of the truck over the entire length where the brakes were to be applied.

The 3-6 week old asphalt pavement had never had any traffic on it, had an ASTM SN_{40} value of 44 to 47 (coefficient of friction), and did not have any striping or markers on it. Each combination ran in the middle of the 37-foot wide pavement and stopped on a -0.41% grade. There was a continuous, relatively

flat two mile section, prior to the braking area for the test truck to achieve the desired speed. The stopping speed was measured with a radar gun and radio communication allowed the driver to increase or decrease his approach speed as appropriate. The Viking driver was instructed to make the stop in the shortest distance possible. This generally resulted in some, but not all, of the wheels locking up.

Only the actual stopping distance was measured from the point of brake application to the actual stopping of the combination. An electro-mechanical gun was attached to the tractor which shot a blank shell when the brake was applied. This allowed recording only the actual stopping distance and did not account for the driver's reaction time.

The results of the braking tests are shown in Fig. 10.

All braking tests for the 2x48 were not completed because of some moderate shifting of the load in the rear trailer. The load (telephone books on pallets) had been bulkheaded to obtain uniform maximum loading. On the first loaded brake test, there was a uniform shifting of the pallets, collapsing the bulkhead, and breaking through the trailer nose. Original speculation that this combination, because of more axle/tires, had a faster deceleration, therefore, breaking loose the pallets, cannot be verified from the data. However, this shifting load does

BRAKING TEST DISTANCES
(Stopping Distances in Feet)

	EMPTY		LOADED	
	DRY	WET	DRY	WET
Triples (2-Axle)				
25 MPH	44.0 Ft.	79.1 Ft.	73.8 Ft.	84.3 Ft.
45 MPH	146.1 Ft.	185.3 Ft.	154.8 Ft. 164.9 Ft.	197.4 Ft.
55 MPH	210.6 Ft.	256.7 Ft.	283.8 Ft.	289.3 Ft.
Triples (3-Axle)				
55 MPH	222.9 Ft.			316.6 Ft.
Rocky Mountain				
25 MPH	43.7 Ft.	47.3 Ft.	46.5 Ft.	49.7 Ft.
45 MPH	134.2 Ft.	164.7 Ft.	143.1 Ft.	155.4 Ft.
55 MPH	197.9 Ft.	248.6 Ft.	212.7 Ft.	
Turnpike				
25 MPH	51.9 Ft.	47.1 Ft.	44.5 Ft.	
45 MPH	167.6 Ft.	154.7 Ft.		
55 MPH	212.3 Ft.	192.8 Ft.		
48-FOOT SEMI				
55 MPH	179.3 Ft.	251.4 Ft.		

Figure 10

indicate that substantial attention should be paid to the actual loading and tie-down procedures.

The 1971 Caltrans Triple Trailer Tests also conducted braking tests. One feature of those 1971 tests was that the trailers always stopped straight, always staying in their lane. This was not uniformly the case on the current tests. In these tests, the combinations varied from stopping straight (no variation), to movement up to 5 feet sideways. Movement occurred to both the right and left, although most variation appeared to the left, the direction of the pavement crossslope. There were a few cases where the driver actually had to ease off the brakes to keep the combination somewhat in line. Fig. 11 gives a more complete listing of the sideways motion or skew of the combinations. These braking tests were all conducted on tangent sections; no tests were conducted on curves. It is not possible to make a categorical statement that under these test conditions LCVs would stop in its own lane.

o Acceleration

Acceleration tests were conducted at the brake test location, just prior to the actual brake tests. From a standing start, the trucks accelerated down the tangent -0.41% grade and attempted to reach 55 MPH in about 4,500 feet. This was not always possible. Measurements were taken using a radar gun and stop watch allowing a time vs. speed comparison for the combinations.

Braking Test Sideways Movement

TRIPLES (COE)

EMPTY

DRY
25 - offset 4 inches to left
45 - rear trailer offset 1-foot to left
55 - last two trailers offset 3 feet to left

WET
25 - rear offset 1-foot to right
45 - rear offset 1-foot to right
55 - middle offset 3-4 feet to left

LOADED

DRY
25 - not recorded
45 - not recorded
55 - not recorded

WET
25 - not recorded
45 - not recorded
55 - not recorded

TRIPLES (CONV.)

EMPTY-DRY-55 - stairstep 3 feet to right

LOADED-WET-55 - not recorded

ROCKY MOUNTAIN DOUBLES

EMPTY

DRY
25 - trailers straight, cab skewed 6-inches to right
45 - generally straight
55 - trailers straight, rear offset 5 feet to left, let off of brakes some

WET
25 - straight
45 - rear of cab skewed 2 feet to left, front/rear line-up
55 - trailers straight, offset 2-3 feet to left

Figure 11

LOADED

DRY
25 - straight
45 - straight
55 - offset 1-foot to right

WET
25 - straight
45 - rear skewed 1-foot to left
55 - no test

TURNPIKE DOUBLES

EMPTY

DRY
25 - some hop, straight
45 - offset 4-5 feet to left, had to ease off brake
55 - trailers straight, offset 10 inches to left

WET
25 - straight
45 - dolly, 1-foot to right
55 - stairstep, 1-2 feet to left

LOADED

DRY
25 - straight
45 - no test
55 - no test

48 Ft. Semi

EMPTY

DRY
55 - trailer straight, offset 2-3 feet to left

WET
55 - trailer straight, offset 4 feet to left

NOTES

Offset - trailer straight in direction of travel, both front and rear moved sideways.

Skew - at an angle to the direction of travel.

Figure 11

The following Figure 12 shows the speed vs. time for three combinations being pulled by HX4272 (340HP). There was not a major difference between the combinations in reaching 30 MPH (30-37 sec.), but there was a significant difference in reaching 50 MPH (54-115 sec.).

There were no major time differences in reaching lower speeds between the different weights; the time difference to reach cruising speeds was significant.

A 5th wheel also took acceleration readings after each combination passed through the Los Banos scales at 3-5 MPH. The driver was not aware that this acceleration was being recorded, so these readings are more representative of the acceleration which would occur during the normal LCV operation. These results are shown in Fig. 13.

o Rain, Splash and Spray

The only significant rain during the test occurred from Altamont Pass (I-580 eastbound) to Westley Roadside Rest (I-5 southbound), a distance of roughly 20 miles, during the loaded RM and 2x48 tests. In this distance, the rain was heavy enough to get a relatively complete picture of how these combinations would operate in the rain on the open road.

Summarily, neither the loaded RM nor the loaded 2x48 experienced any handling problems during this period because of the wet pavement itself.

ACCELERATION TESTS

(Speed vs. Time)

MPH	ROCKY MOUNTAIN LOADED (106,850)	TURNPIKE EMPTY (50,200)	TURNPIKE LOADED (122,650)
5			
10	10 Seconds	8 Seconds	10 Seconds
15	14 Seconds	12 Seconds	16 Seconds
20	20 Seconds	16 Seconds	22 Seconds
25	28 Seconds	22 Seconds	29 Seconds
30	35 Seconds	30 Seconds	37 Seconds
35		33 Seconds	44 Seconds
40	52 Seconds	40 Seconds	58 Seconds
45	64 Seconds	44 Seconds	70 Seconds
50	78 Seconds	54 Seconds	115 Seconds
55		62 Seconds	

NOTE:

All runs with Ford tractor, HX4272, 340HP

Figure 12

ACCELERATION AT LOS BANOS SCALES

Distance Past Scales	Rocky Mountain Doubles	Turnpike Doubles	Ave. 5-Axle Truck
500 Ft.	14 MPH		23 MPH
1,000	24 MPH	34 MPH	32 MPH
1,500	31 MPH	34 MPH	37 MPH
2,000	33 MPH	37 MPH	42 MPH
2,500	41 MPH	39 MPH	45 MPH
3,000	40 MPH	39 MPH	48 MPH
3,500	43 MPH	45 MPH	49 MPH
4,000	44 MPH	48 MPH	51 MPH
4,500	47 MPH	50 MPH	53 MPH

NOTE: Both RM & 2x48 pulled by HX4272 while loaded.

Figure 13

The RM had no spray deflectors on the 48-foot trailer, but did have bolted-on spray deflectors on the 28-foot (Oregon Triple) trailer. The test crew and observers were unanimous in their praise of the effectiveness of the spray deflectors and, considering their simplicity, the need to have them on all van and flatbed trailers. There was a major difference in the spray generated by the two trailers. It was not unusual for an auto passing the RM to pass the 28-foot trailer at normal speed and then hesitate, observe, or even retreat, when starting to pass the 48-foot trailer. There was also a significant observed difference in the spray generated by other passing, nondeflectorized large trucks and deflectorized 28-foot trailers.

Neither 48-foot trailer originally had spray deflectors. With the threat of rain, deflectors were added to the 2x48. These temporary, homemade deflectors consisted of cutting the bolt-on type deflectors in half lengthwise (total height approximately 2-inches) and attaching them to the trailers with S-shaped hooks. The S-hook arrangement actually allowed the deflectors to swing, an advantage when placed over the tractor and dolly wheels, and when changing tires. The homemade deflectors worked almost as well in deflecting the spray as the permanent units on the 28-foot trailer. Based only on observations, it appeared these deflectors would have worked as well if they had been 1/2 inch higher (total height 2.5 inches) and if they had been long enough to fully cover the duals (original deflectors designed only to cover single axles). The entire operation to make and

connect the homemade deflectors took less than one hour, but they cannot be considered to be a permanent installation.

o Wind

The test crew was ready to measure the wind speed and observe each empty combination on I-680 between the Benecia Bridge and I-80. This area contains a large windmill farm, is signed as a wind area, and the wind normally blows perpendicular to I-680. The highest recorded windspeed, however, was 8 MPH. This low windspeed did not allow observations of how the empty LCVs handle in a wind situation.

o Noise

Noise readings were made during the operation of the loaded Triples test. The readings were made at six locations of both the test truck and a representative sample of other large trucks. The readings were made 50 feet from the truck lane, and were made on both flat terrain and on grades. The results of these readings are shown in Fig. 14.

The noise emissions of the Triples were not unusually high or low compared to the noise emission of other trucks. Non-measured observations of the other two combinations (even with BR1) had noise levels comparable to the Triples.

NOISE MEASUREMENTS

LOCATION	PERCENT PROFILE GRADE	TRUCK SPEED	PEAK NOISE DBA	RANGE & NO. OF OTHER TRUCKS MEASURED
Altamont Pass, I-580 EB	+4 %	28	83.5	80-90, 50
2 Mi. South of Santa Nella, I-5 SB	0	(Estimate) 55-60	84.0	75-90, 8
13 Mi. North of Rte. 198, I-5 SB	0	(Estimate) 55-60	84.0	
Grapevine, I-5 SB	+6 %	16	83.0	78-87, 50
1 Mi. North of Lerdo Hwy., Rte. 99 NB	0	(Estimate) 55-60	84.5	83-89, 6
Rte. 198 Junction, Rte. 99 NB	0	(Estimate) 55-60	82.0	83-85, 5

NOTES:

1. For COE Triple Trailers
2. Microphone 50 feet from travel lane, 5 feet above pavement

Figure 14

o Fuel Economy

While not strictly controlled for test purposes, fuel usage and mileage were recorded each time fuel was added. The approximate fuel economy is shown in Fig. 15.

CONCLUSIONS

A variety of conclusions are possible when comparing the tested LCVs to other, existing 5-axle trucks. In some cases there was little difference; this includes such areas as braking, splash and spray, narrow lanes, 2-lane roads, and noise generation.

In some cases there was a difference between the test trucks and other trucks, but generally not between the combinations tested. This includes such areas as urban freeways and arterials, freeway facilities, grades, and acceleration. These areas point out the lengths and weights of the LCVs on the whole are substantially different from other large trucks.

In some cases, there is not only a difference generally between the tested trucks and other 5-axle trucks, but differences also exist between the combinations tested. This includes such areas as freeway interchanges, open road, intersections, and off-tracking. These cases point out there are actually differences in the handling characteristics of each combination tested.

FUEL ECONOMY

MILEAGE	FUEL	MPG	TRACTOR/ROUTING
			HD-4176
160	34.8	4.6	Empty Triples, Bay Area Loop
305	90.0	3.4	Loaded Triples, Santa Clara/ Bakersfield
379	140.0	2.7	Loaded Triples, Bakersfield/LA/ Fresno
189	48.0	3.9	Loaded Triples, Fresno/Santa Clara
			HX-4272
182	31.0	5.9	Empty RM, Bay Area Loop
573	145.0	4.0	Loaded RM, Santa Clara/Bakersfield/ Fresno (1)
201	50.0	4.0	Loaded RM, Fresno/Santa Clara
			HX-4272
408	120.0	3.4	Loaded 2X48, Santa Clara/ Bakersfield/Fresno
267	80.0	3.3	Loaded 2X48, Fresno/Santa Clara
			BR-1
380	106.0	3.6	Loaded 2X48, Bakersfield/LA/ Bakersfield (2)

NOTES:

(1) Includes run to Frazier Park and return to Bakersfield

(2) Includes tractor only run Fresno/Bakersfield (120 Miles)

Figure 15

Each combination had some characteristic which could prevent its universal operation. The Triples had a constant sway in the combination which could create problems in dense traffic conditions, and created a reaction from adjacent traffic. The Triples, however, proved as maneuverable as the largest combinations currently legal in California for operation on the Designated System.

The Rocky Mountain Doubles had none of the open road problems experienced by the Triples, but rather had a more difficult time maneuvering through existing interchanges and intersections. The RMs proved less maneuverable than the largest combinations currently legal in California. This could result in greatly increased pavement edge damage or roadside equipment damage.

The Turnpike Doubles also proved very stable on the open road, but were even less maneuverable than the RMs. The 2x48 could not successfully maneuver within some interchanges of the latest design, and actually used more room than was paved. This again would result in the pavement edge damage, but more severe than the other combinations.

These handling characteristics were magnified when the test trucks were off of the freeways in urban areas. In such situations where the LCVs' length and weight characteristics separate them from other large, 5-axle trucks, either special provisions will need to be made for the LCVs or thought should be given to instituting special operating limitations and conditions.

APPENDIX A

ITINERARY

LONGER TRUCK OPERATIONAL TESTS

DAY 1

10:00 am: Safety inspection (CHP); vehicle measurement and specifications

- Viking Freight Yard, 3405 Victor Street, Santa Clara

12:00 noon (or when available): Open road, wind and urban tests

- Route 101 SB (101/DeLaCruz R = ?)
- Route 680 NB
  - o 11 ft lanes Monument-Rte 242
  - o 10 ft lanes Benecia Bridge, 1000 ft N/O toll plaza
  - o Wind observations north of Route 780
- Route 80 EB
- Abernathy Road, turnaround
- Route 80 WB
  - o Cordelia truck stop
- Route 17 SB
  - o Left hand off at I-80
- Montague Expressway to Viking Yard

NOTES:

- All runs empty
- Bridge tolls required
- Aerial filming of: 1) wind tests, 2) from north of Carquinez Bridge to Hayward, and 3) Route 17 to Viking Yard
- Two runs of triples: first using a 2-axle cabover, to be done this timeframe; second using a 3-axle conventional, to be done Day 2 in place of acceleration and braking tests
- Empty axle weights recorded on Viking scales

DAY 2

8:00 am: Acceleration and braking tests

- Route 101 construction near Morgan Hill
  - o Tests between Sta 1450 and 1470 (±0.125% grade, 36 ft pavement plus 5 and 10 ft shoulders plus 84 ft median)

o Montague Expressway, Route 17 SB, Route 101 SB (17 SB - 101 SB R = 150 ft), turnaround at Coyote scales, Bernal Ave ramps to east of existing Route 101

NOTES:

- All tests run empty and full, dry and wet pavement
- Triples to be tested with both 3-axle conventional and 2-axle cabover
- Rocky Mountains to be run with and without 28 ft trailers to get 48 ft semi characteristics
- Skid test (ASTM E-274-6ST) to be conducted on same segment
- Triples braking tests to be conducted 11/22/83

3:00 pm (or when available): Off tracking test

- Viking Freight Yard

NOTES:

- Rocky Mountains to be run with and without 28 ft trailers to get 48 ft semi characteristics
- Off tracking from 60, 80, 100 ft radius curves over 180° central angle
- Triples to be run with both 3-axle conventional and 2-axle cabover

DAY 3

7:00 am: Open road, grade and access tests

- Route 17 NB (from Montague Expressway; 17/Montague R = ?)
- Route 580 EB

o Altamont Grade speed tests
o Brake inspection stop

- Route 5 SB

  o Westley SRRA
  o Access to Mid California Truck Stop, Route 33, east side of Route 5

- Route 198 EB (some 2-lane sections, on larger truck route)

- Route 99 SB to Viking Yard in Bakersfield

NOTES:

- All runs loaded

- Triples to be run with 2-axle conventional

DAY 4

8:00 am: Grade, narrow lanes tests

- Route 99 SB
- Route 5 SB
  o Grapevine speed tests
  o Brake inspection sto
  o Left hand off at route 170 junction
    - Route 10 EB
    - Route 605 SB (5/605 SB/NB R = 200 ft)
    - Route 5 NB
    - Route 10 WB
    - Route 405 NB
    - Route 5 NB
  o Access Lebec SRRA NB
  o Brake inspection
    - Route 99 NB to Bakersfield, Viking Yard

NOTES:

- 11 ft lanes:

  Route 5 SB: 3 segments, total = 2.9 mi
  Route 10 EB: 2 segments, total = 2.6 mi
  Route 5 NB: 2 segments, total = 4.6 mi
  Route 10 WB: 4 segments, total = 5.1 mi
  Route 405 NB: 1 segment, total = 9.3 mi

- All runs loaded

- Aerial photography on loop beginning at 5/605 and ending near 101/405

DAY 5

7:00 am: Open road and access tests

- Route 99 NB
  - o Access truck stop, south of 7th Standard Road (06-Ker-99, PM 30.53), west of freeway
  - o Access Viking's Modesto Yard, 1760 Crows Landing Road, approximately 1.5 miles west of Route 99 (exit via Hatch Road, enter 99 NB via Crows Landing Road)
  - o Access Jimco Truck Plaza, Jack Tone Road, 10-SJ-99, PM 2.4
- Route 120 WB (not a larger truck route)
- Route 205 WB
- Route 580 WB
- Route 680 SB
- Viking Santa Clara Yard

NOTES:

- Empty or loaded at Viking's discretion

SCHEDULE

	Day 1	Day 2	Day 3	Day 4	Day 5
Run 1 (Triples)	10/24	10/25	10/26	10/27	10/28
Run 2 (Rocky Mountains)	11/7	11/8	11/9	--	11/10
Run 3 (Turnpike Doubles)	11/14	11/15	11/16	11/17	11/18

NOTES:

- Rocky Mountain Doubles are not to run narrow lanes tests: Schedule modified as follows:

Day 3

- Route 5 SB
  - o Access Mid California Truck Stop
  - o Grapevine speed tests
  - o Turnaround at Gorman
  - o Access Lebec SRRA NB
- Route 99 NB to Bakersfield

Day 4

Same as Day 5 for other runs

ALL RUNS

- Truck mileage and fuel consumption to be recorded for each combination
- Noise measurements during acceleration/braking, grade and selected run bys
- All weights to be recorded at Viking's Santa Clara Yard and CHP scales as appropriate.

FORMULA B -- TRIPLES

AXLE COMB.	NO. AXLES	DISTANCE	FORMULA B ALLOWABLE	LOADED WEIGHT
1-2	2	10.0	40,000 (32,500*)	28,800
1-3	3	31.9	60,000 (52,500*)	46,900
1-4	4	41.1	69,500 (71,500*)	65,000
1-5	5	63.4	87,400 (90,000*)	82,100
1-6	6	72.6	97,800 (99,900*)	96,600
1-7	7	94.9	115,400 (117,500*)	111,000
2-3	2	21.9	40,000	37,600
2-4	3	31.1	59,000	55,700
2-5	4	53.4	77,500	72,800
2-6	5	62.6	87,400	87,300 CONTROL
2-7	6	84.9	105,000	101,700
3-4	2	9.2	39,000	36,200
3-5	3	31.5	60,000	53,300
3-6	4	40.7	69,500	67,800
3-7	5	63.0	84,700	82,200
4-5	2	22.3	40,000	35,200
4-6	3	31.5	60,000	49,700
4-7	4	53.8	78,000	64,100
5-6	2	9.2	39,000	31,600
5-7	3	31.5	60,000	46,000
6-7	2	22.3	40,000	28,900

*Based on 12,500 lb. steering axle limit
(e.g., ((1-4) = (2-4) + 12,500)

FORMULA B -- ROCKY MOUNTAIN

AXLE COMB.	NO. AXLES	DISTANCE	FORMULA B ALLOWABLE	LOADED WEIGHT
1-2	2	13.5	40,000 (32,500*)	26,750
1-3	3	17.5	49,500 (46,500*)	42,650
1-4	4	50.7	76,000 (72,500*)	57,800
1-5	5	54.8	82,400 (82,000*)	72,950
1-6	6	65.6	93,600 (93,000*)	89,400
1-7	7	87.9	111,300 (111,500*)	106,850
2-3	2	4.1	34,000	31,800
2-4	3	37.3	60,000	46,950
2-5	4	41.4	69,500	62,100
2-6	5	52.2	80,500	78,550
2-7	6	74.5	99,000	96,000
3-4	2	33.2	40,000	31,050
3-5	3	37.3	60,000	46,200
3-6	4	48.1	74,000	62,650
3-7	5	70.4	91,800	80,100
4-5	2	4.1	34,000	30,300
4-6	3	14.9	47,000	46,750 CONTROL
4-7	4	37.2	60,000	64,200
5-6	2	10.8	40,000	31,600
5-7	3	33.1	60,000	49,050
6-7	2	22.3	40,000	33,900

*Based on 12,500 lb. steering axle limit

FORMULA B -- TURNPIKE

AXLE COMB.	NO. AXLES	DISTANCE	FORMULA B ALLOWABLE	LOADED WEIGHT
1-2	2	13.5	40,000 (32,500*)	26,675
1-3	3	17.6	49,500 (46,500*)	42,550
1-4	4	50.8	76,000 (72,500*)	57,750
1-5	5	54.9	82,400 (82,000*)	72,950
1-6	6	65.8	93,600 (93,000*)	83,300
1-7	7	69.9	100,800 (100,100*)	93,650
1-8	8	103.6	125,400 (125,000*)	108,150
1-9	9	107.7	132,600 (132,200*)	122,650
2-3	2	4.1	34,000	31,750 CONTROL
2-4	3	37.3	60,000	46,950
2-5	4	41.4	69,500	62,150
2-6	5	52.3	80,500	72,500
2-7	6	56.4	87,600	82,850
2-8	7	90.1	112,500	97,350
2-9	8	94.2	119,700	111,850
3-4	2	33.2	40,000	31,075
3-5	3	37.3	60,000	46,275
3-6	4	48.2	74,000	56,625
3-7	5	52.3	80,500	66,975
3-8	6	86.0	105,600	81,475
3-9	7	90.1	112,500	95,975
4-5	2	4.1	34,000	30,400
4-6	3	15.0	47,000	40,750
4-7	4	19.1	54,500	51,100
4-8	5	52.8	81,100	65,600
4-9	6	56.9	88,200	80,100
5-6	2	10.9	40,000	25,550
5-7	3	15.0	47,000	35,900
5-8	4	48.7	74,500	50,400
5-9	5	52.8	81,100	64,900
6-7	2	4.1	34,000	20,700
6-8	3	37.8	60,000	35,200
6-9	4	41.9	70,000	49,700
7-8	2	33.7	40,000	24,850
7-9	3	37.8	60,000	39,350
8-9	2	4.1	34,000	29,000

INTERCHANGE MOVEMENTS

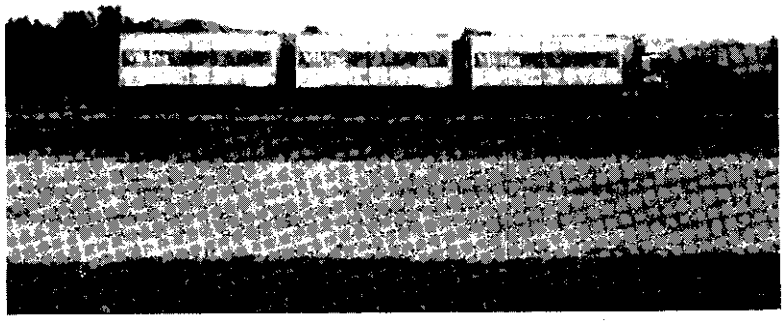
	3X	RM	2X48
Trimble ———> 101 SB (Loop)	X	X	X
I-680 ———> Walnut Creek Scales (NB)	X	X	X
I-680 EB ———> Cordelia Scales	X	X	X
I-80 EB ———> Abernathy NB (Loop)*	X	X	X
Abernathy NB ———> I-80 WB (Lt. Turn)	X	X	X
I-80 WB ———> Cordelia Scales	X	X	X
I-80 WB ———> Cordelia Truck Stop *	X	X	X
Cordelia Truck Stop ———> I-80 WB	X	X	X
I-80 WB ———> Rte. 17 SB (Lt. Hand Off)	X	X	X
Rte. 17 SB ———> Montague Expressway*	X	X	X
Montague EB ———> I-680 NB (Loop)	X	X	X
I-680 NB ———> I-580 EB	X	X	X
I-580 EB ———> Livermore Scales	X	X	X
I-580 EB ———> Brake Inspection Area* (Altamont)	X	X	X
I-580 EB ———> Westley SRRA	X	X	X
I-5 SB ———> Los Banos Scales	X	X	X
I-5 SB ———> Rte. 33 EB (Santa Nella, Left Turn)*	X	X	X
Rte. 33 WB ———> I-5 SB (Loop)	X	X	X
I-5 SB ———> Rte. 198 EB (Lt. Turn)*	X	X	X
Rte. 198 EB ———> Rte. 99 SB	X		X
Rte. 99 SB ———> Rte. 58 WB*	X		X
Rte. 198 WB ———> I-5 SB (Lt. Turn)*		X	
I-5 SB ———> Frazier Park EB*		X	
Frazier Park EB ———> I-5 NB*		X	

	3X	RM	2X48
Rte. 58 EB ———> Rte. 99 SB*	X	X	X
I-5 SB ———> Wheeler Ridge Scales	X	X	X
Rte. 99 SB ———> I-5 SB	X		X
I-5 SB ———> I-10 EB	X		X
I-10 EB ———> I-605 SB	X		X
I-605 SB ———> I-5 NB	X		X
I-5 NB ———> I-10 WB	X		X
I-10 WB ———> I-405 NB	X		X
I-405 NB ———> I-5 NB	X		X
I-5 NB ———> Castaic Scales	X		X
I-5 NB ———> Lebec SRRA	X	X	X
I-5 NB ———> Route 99 NB	X	X	X
Rte. 99 NB ———> Rte. 58 WB (Lt. Turn)*	X	X	X
Rte. 58 EB ———> Rte. 99 NB (Lt. Turn)*	X	X	X
Rte. 99 NB ———> 7th Std. Rd. WB (Lt. Turn)*	X	X	X
7th Std. EB ———> Rte. 99 NB (Loop)*	X	X	X
Rte. 99 NB ———> Chestnut NB (Fresno)*	X	X	X
Central WB ———> Rte. 99 NB (Rt. Turn)*	X	X	X
Rte. 99 NB ———> Hatch WB (Loop, Rt. Turn)*	X	X	X
Crows Landing NB ———> Rte. 99 NB (Loop)*	X	X	X
Rte. 99 NB ———> Jack Tone Rd. SB (Loop)*	X	X	X
Jack Tone Rd. NB ———> Rte. 99 NB (Lt. Turn)*	X	X	X
Rte. 99 NB ———> Rte. 120 WB	X	X	X
Rte. 120 WB ———> I-205 WB	X	X	X

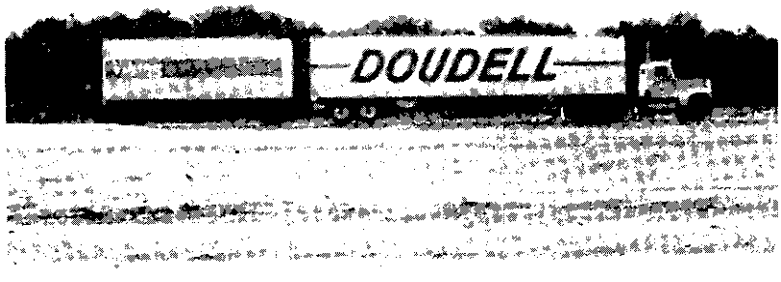
(Begins or ends with at-grade intersection.

INTERSECTION MOVEMENTS

	3X	RM	2X48
De La Cruz ———> Trimble (Lt. Turn)	X	X	X
De La Cruz ———> Trimble (Rt. Turn)	X	X	X
Montague WB ———> Trimble WB (3-Lane Left-Turn Pocket)	X	X	X
Trimble ———> De La Cruz (Lt. Turn)	X	X	X
Trimble ———> De La Cruz (Rt. Turn, Islands)	X	X	X
Route 58 WB ———> Gibson NB (Rt. Turn)	X	X	X
Gibson NB ———> Gilmore EB (Rt. Turn)	X	X	X
Gilmore EB ———> Standard NB (Lt. Turn)	X	X	X
Standard SB ———> Gilmore WB (Rt. Turn)	X	X	X
Gilmore WB ———> Gibson SB (Lt. Turn)	X	X	X
Gilmore SB ———> Route 58 EB (Lt. Turn)	X	X	X
7th Standard WB ———> Norris Rd. SB (Lt. Turn)	X	X	X
Norris Rd. NB ———> 7th Std. EB (Rt. Turn)	X	X	X
Hatch WB ———> Crows Landing SB (Lt. Turn)	X	X	X



TRIPLE TRAILERS



ROCKY MOUNTAIN DOUBLES

TURNPIKE DOUBLES